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BURROWING ACTIVITIES OF THE SCORPION *ANUROCTONUS PHAEODACTYLUS* (WOOD) (SCORPIONIDA: VEJOVIDAE)

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Abstract: Burrowing activities of the scorpion, *Anuroctonus phaeodactylus* (Wood), were studied in both laboratory and field situations. This scorpion exhibits a wide and disjunct distribution in Central and North America. Within a favorable area noticeable habitat preference was shown in that the population is represented by many isolated demes. *A. phaeodactylus* exhibits a unique, very specialized, and obligate burrowing habit. A specialized behavior called "sponge bathing," utilized to keep the appendages clean and free of obstruction was described and related to burrowing.

Introduction

The scorpion *Anuroctonus phaeodactylus* (Wood) is a successfully adapted species to a wide geographical area of North and Central America. One of the most important adaptations seems to be a set of unique and specialized burrowing activities. The main purpose of this paper is to describe the activities associated with burrowing in this species so that comparisons with other species will be possible in relation to burrowing behavior and to their respective ecologies.

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Methods. To gain an understanding of the burrowing activities of *A. phaeodactylus*, studies were carried out in the field wherever possible. All field

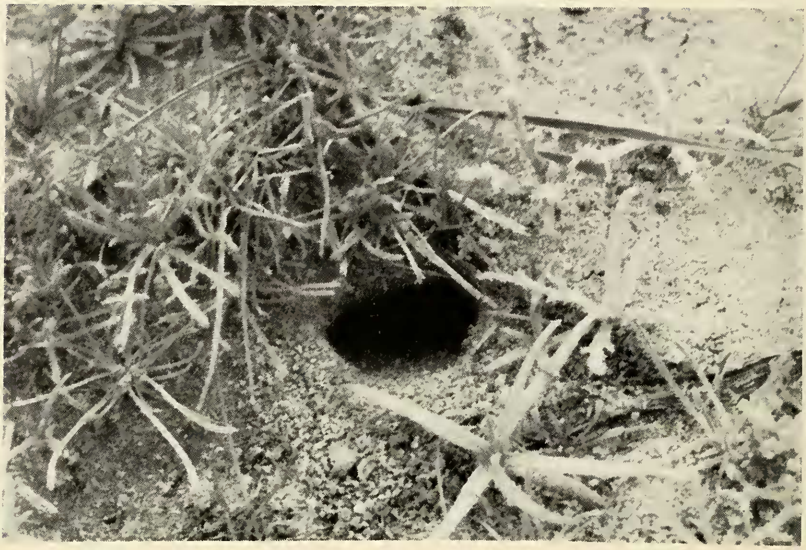

Figure 1. Typical entrance to *Anuroctonus phaeodactylus* burrow. Note the characteristic oval entrance, and tumulus below.

studies took place in San Diego County, California, in four localities: Balboa Park and Mount Soledad (both in the city of San Diego), Lakeside, and Wildcat Canyon near Lakeside. For studies on burrow construction and "sponge bathing" it was necessary to stage a natural environment in the laboratory. The morphology of burrows was studied by careful excavation and also by making castings. Data on migratory studies were obtained by use of 1-gallon unbaited pitfall traps. Each of these traps had an open diameter of 6¼ inches. Each trap was permanently buried with its open end flush with the ground surface and covered with a loose-fitting rock.

Distribution and habitat preference. *Anuroctonus phaeodactylus* occurs throughout North America where deep, well packed sedimentary soils are found in conjunction with relatively arid conditions. The populations are noticeably disjunct. Distribution reports have come from the following areas: Utah (Wood, 1863), southern California (Comstock, 1940), Virginia (Pocock, 1902), Colorado (Pocock, 1902), Baja California, Mexico (Hoffmann, 1931), and Guatemala (Pocock, 1902).

Anuroctonus phaeodactylus occurs extensively in chaparral areas of southern California where studies of habitat preference were conducted in San Diego County. The presence of this species was detected by locating the entrance to a burrow followed by excavation of the inhabitant for verification. *Anuroctonus phaeodactylus* populations were found to exhibit a high degree of aggregation

Table 1. *Some measurements (in cm.) of 25 specimens of* A. phaeodactylus *burrows from Lakeside, San Diego County, California.*

Measurement	Minimum	Maximum	Average
Entrance width	1.2	3.6	2.2
Entrance height	1.0	3.1	2.0
Vertical depth (females and immatures)	19	37	29
Vertical depth (four adult males)	13	19	15
Burrow length	18	42	32
Terminal chamber length	3.6	8.0	6.2
Terminal chamber width	2.0	6.2	4.0

in that they are not distributed at random, but occur in scattered but relatively dense colonies. This species was collected along the coast in canyons at La Jolla overlooking the ocean, in canyons of Balboa Park inland in the foothills of Dulzura, on slopes in Ramona, El Cajon, Lakeside, and even high in the Cuyamaca Mountains. In general, sloping sedimentary hillsides covered with sparse plant cover were preferred. In these areas they aggregated on slopes with a southeast exposure to the sun. The greatest abundance was observed in areas where chaparral cover had been periodically burned. It is rare to find a burrow in a valley or canyon bottom, or in level ground.

Description of burrow. The burrow is a simple tunnel having an oval entrance which penetrates the ground with an angle of 30 to 35 degrees from the horizontal (fig. 1), makes a series of characteristic turns, and finally ends in a somewhat enlarged terminal chamber or nest. No side tunnels or other entrances are constructed. The terminal chamber is normally elevated about 2 cm. above the end of the tunnel proper. To determine the variation existing among burrows, 25 were excavated and measured (table 1). All burrows were remarkably similar, variation being due primarily to size and sex of the inhabitants. Twenty-one burrows were occupied by females and immature males, while four were occupied by mature males (determined by presence of sex bulb). Burrows of these four males were always considerably more shallow than those of the females, being never deeper than 19 cm. Every burrow was occupied, and by only one scorpion.

Burrow construction. The behavior exhibited in burrow construction is very specialized, and consists of five steps: search for suitable site, soil loosening, soil transport, deposit of excavated soil, and shaping and packing the burrow.

Before any excavation is begun, the scorpion appears to examine all the available surface thoroughly. The site of the burrow is normally on a slope where the soil is suitably packed.

Packed soil is loosened at the site of excavation by a chewing action of both chelicerae. The loosened soil is then dug out and gathered by the first pair of walking legs. These legs are used rapidly and skillfully, much like "hands." The pedipalps are generally not used in digging other than for support. The chelicerae are frequently brushed clean by the first pair of walking legs. After the loosened soil is gathered into a small mound by the first legs in preparation for transport, it is dragged, as in a reverse bulldozing action, out of the burrow. The mound is held intact at its lower limits by the first pair of legs as the scorpion backs out of the burrow using the last pairs of legs as the source of locomotion and support. An initial push with the flexed pedipalps may occur as the scorpion begins to move the soil. While transporting the soil, the femur is always horizontal, the patella is vertical, and the tibia, two tarsomeres, and pretarsus are held horizontal on the burrow floor. The load of soil is dragged through the burrow entrance to a tumulus about 7 cm. away where it is deposited. Occasionally the soil is dropped shortly before reaching the tumulus, and is then pushed to the tumulus by a pushing action of the telson and metasoma. This behavior keeps the path well graded, smooth, and level. On occasion, accumulation of excavated soil around the burrow entrance may hinder the burrowing behavior. In this case the soil is transported by dragging as far as possible toward the tumulus, then it is kicked back vigorously by the first two pairs of walking legs as the scorpion stilts high on the hind two pairs. Occasionally a rock needs to be transported from the burrow. In this case it is carried, if small, or rolled, if large, by the first two pairs of legs in the manner described above.

The floor of the burrow is kept smooth and even by the method of soil transport. About every 5 minutes the ceiling and sides of the burrow are smoothed and packed by manipulations of the tail, which is wedged in various ways so that muscular contractions exert pressure, by lever action, against the walls of the burrow. This not only serves to give the burrow its characteristic shape, but also serves to strengthen it.

While burrowing, scorpions may work continuously for 5 or 6 hours, and if just beginning to dig may excavate a burrow to a depth of 2.5 cm. with a width of 1.5 cm. within 30 minutes. The actual speed of excavation in natural habitats is a function of the soil packing and texture. Burrowing occurred at all hours in the laboratory.

MAINTENANCE OF THE PERMANENT BURROW. Field and laboratory studies indicate that maintenance work on the burrow is a continuous process. Maintenance activities consisted of removal of soil from cave-ins, removal of prey remains, and repacking of the burrow walls when necessary. Evidence in the field of fresh burrowing or burrow maintenance occurred during every month of the year, as judged by inspection of fresh soil in the tumulus. However, such burrowing activity occurred mostly after disturbance of the ground surface, as by rain, fire, or trampling.

TABLE 2. *Total numbers of specimens of* A. phaeodactylus *collected by 61 pitfall traps throughout the year (April 4, 1962, to April 7, 1963). Traps were permanently set and checked weekly in Wildcat Canyon, San Diego County, California. All scorpions were sexually mature males.*

Dates	Number
4/4 to 4/29	4
4/29 to 5/27	5
5/27 to 6/24	6
6/24 to 7/22	4
7/22 to 8/29	5
8/29 to 9/24	8
9/24 to 10/22	1
10/22 to 11/19	0
11/19 to 12/17	0
12/17 to 1/14	0
1/14 to 2/11	0
2/11 to 3/11	0
3/11 to 4/7	0
Total	33

INITIATION OF BURROWING AND BURROW HABITATION. In the laboratory, burrowing activities first began during the second-instar stage of development. Thirteen babies were born August 23, 1965, molted to second-instar September 9, and were first observed digging in their cage October 24 (61 days after birth). Prior to initiation of the burrowing behavior the young scorpions sought shelter under rocks or the water dish. Earlier burrowing would not have been possible because the cuticle had not attained the necessary degree of hardness. Observation indicates that burrowing occurs throughout the life of this species after its initiation with the exception of adult males.

MIGRATORY HABITS.* To investigate any migratory habits which might occur within an *A. phaeodactylus* population, 61 unbaited pitfall traps were permanently set in the Wildcat Canyon study area. These traps were checked every 7 days for 1 year. Each week the scorpion catch was recorded and each scorpion was sexed. During this time the traps collected 33 scorpions, all of which were sexually mature males (table 2). It should be noted that no females or immature males were collected even though their burrows occurred in the study area with a high frequency. These data indicate that sexually mature males are active migrators from April through October, and that immature males and females do not migrate, but remain in their burrows. This male migration is probably linked to mating activities. The mature males presumably seek out the burrows of suitable females and there mate.

* Migration here refers to transient or roving activities as contrasted with stay-at-home burrowing behavior.

A study quadrate of 1 square yard, containing three active burrows, was staked out and observed in the field to determine if the inhabitants altered or left their burrows. Five pit traps were placed around the periphery of the quadrate to catch any scorpion roaming away from its burrow. The three quadrate burrows were observed regularly from October, 1962, until February, 1963, at which time they were accidentally destroyed by hunters. During this time continuous occupancy, judged by freshly excavated soil in the tumulus, was apparent. The traps associated with the quadrate failed to catch the inhabitants.

From these observations, it is apparent that the burrows were occupied in a permanent manner for long periods of time if not throughout most of the life cycle. This conclusion is also supported by the fact that the finding of an abandoned (unoccupied) burrow is a very rare event.

SYMBIOTIC RELATIONS AND PREDATORS. The entrance, tunnel, and nest were found exceptionally clean and free of loose soil, rocks, and remains of prey. However, in a few nests pieces of moss and fresh remains of prey were found. A number of other living organisms were also excavated from the burrows which included: spiders, Jerusalem crickets, isopods, beetle larvae, and collembolans. Most of these were collected from the nest region. In one nest over 10 small spiders were found. In all cases, the organisms sharing the burrow were minute in size, larger ones presumably would have been preyed upon by the scorpion.

Only four organisms have been observed to prey upon *A. phaeodactylus*. These are: desert shrews (*Notiosorex crawfordii*), Jerusalem crickets (*Stenopelmatus* sp.), darkling beetles (*Eleodes grandicollis*), and several species of owls. The burrow serves as good protection from both *Eleodes* and *Notiosorex*, which are too large to navigate the tunnel. *Stenopelmatus*, on the other hand, may enter the burrow, there having about a 50 percent chance of overcoming the scorpion. Though the burrow serves to protect the scorpion from owls, these predators still take numbers of these scorpions. Examination of *A. phaeodactylus* remains around barn-owl nests indicate that the catch is almost exclusively composed of sexually mature males.

SPONGE BATHING. "Sponge bathing" was first described in scorpions by Baerg (1954). As described, a scorpion will place its telson in its preoral cavity, wet it with exudate, then dab this substance over its body. *Anuroctonus phaeodactylus* exhibits a high degree of this activity, but does it very differently than described by Baerg with his Jamaican species.

"Sponge bathing" in *A. phaeodactylus* is most commonly observed during and after burrowing as well as shortly following the drinking of water. During these times, the scorpion may spend as long as 1 hour cleaning its body, primarily the pedipalps, chelicerae, and first two pairs of walking legs. "Sponge bathing" was observed in the laboratory to occur day and night, at all times of the year.

The exudate used is a clear watery fluid which is exuded in large quantities into the preoral cavity. Although large amounts are present, little is lost to the substrate as its surface tension is sufficiently strong to contain it between the gnathobases and on the chelicerae.

The fluid is applied to the pedipalps by placing the distal end of these appendages into the preoral cavity, one at a time, and massaging them with the chelicerae. The chelicerae are moistened during this process because of their close association with the preoral cavity. The tarsal and pretarsal regions of the first two pairs of walking legs are then brought to the ventral aspect of the gnathobases and moistened. The tarsal segments then moisten the coxal and trochanter segments of these legs by rubbing action. The pubescent tarsi are carefully worked, and cleaned by rubbing these segments together as a person would wash his hands. The tarsi of the first pair of legs were the most vigorously and carefully worked. The tarsi of the second pair of legs also received much attention, and the tarsi of the third were also occasionally worked. This activity was never observed with the fourth pair of walking legs. The last pair was used as the primary means of support during this process, maintaining the scorpion's body in a stilting position above the substrate.

By far the most actively used appendages in "sponge bathing" were the chelicerae. They were constantly dabbing exudate, rubbing, and combing the numerous hairs of the pedipalps. Periodically the chelicerae would stop massaging the other appendages and massage each other. At this time the chelate parts would carefully comb the dense brush-like fringe of hairs on the homologue. This being done, they would immediately resume their previous work.

Frequently the first two pairs of walking legs would begin to vibrate or shake back and forth. This was interpreted as a muscular behavior necessary to activate the pharyngeal pump, and thereby supply more exudate. The most logical source of the exudate would be the extensive glands of the mesenteron. If this is actually the true source there is a good chance that this exudate may contain digestive enzymes, and be the same or similar to the exudate used during feeding.

"Sponge bathing" behavior is interpreted as a means of cleaning the scorpion's body parts which may become coated with mud, dirt, or various films. It would be especially important to keep the body regions, which are well supplied with sensory receptors, clean and free from substances which might interfere with their functions. Since the pedipalps, first two pairs of walking legs, chelicerae, and telson are most actively cleaned, it seems that sensory receptors may be most numerous and important in these regions. Also, these are the regions of the body which come in greatest contact with the substrate during burrowing and other daily activities. For this reason they would have the greatest chance of becoming coated with mud or other obstructions.

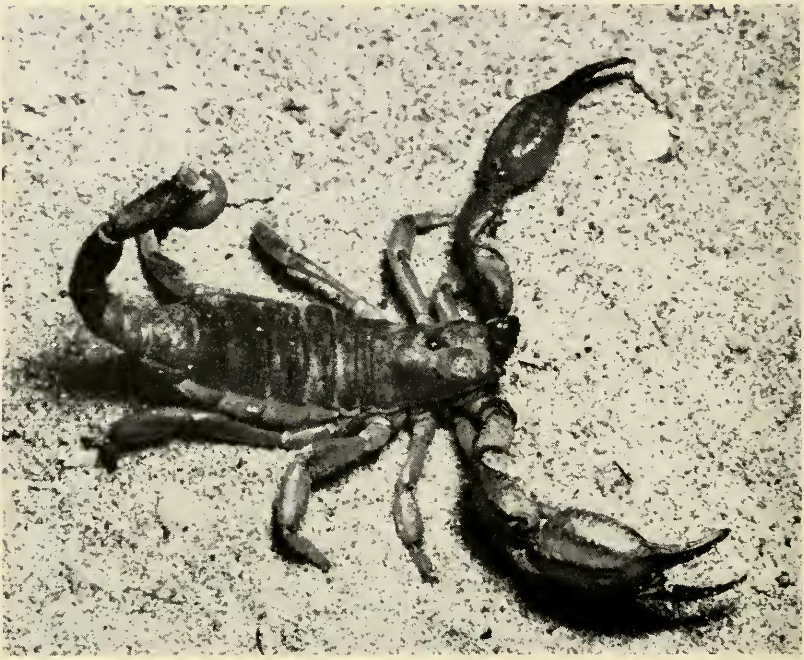

FIGURE 2. *Anuroctonus phaeodactylus* showing general external morphology.

MORPHOLOGICAL SPECIALIZATION IN RELATION TO BURROWING. The morphology of this scorpion is distinct from other southwestern species (fig. 2). In general, the morphology reflects the demands of a specialized burrowing way of life. The pectines, which typically are very long and with many teeth in southwestern vejovids, are reduced in both size and tooth count in this species. The behavior in regard to pectine use is also distinctive. *Anuroctonus phaeodactylus* often drags the pectines continuously over the substrate, while roving vejovids, such as *Hadrurus*, merely brush the distal margin of the pectinal teeth against the substrate periodically while walking.

The pedipalps are distinctively thick, heavy, and powerful. These are used effectively for defense within the burrow, as well as for the primary means of catching and immobilizing the prey. This pedipalp enlargement is correlated with a reduction in the size of the metasoma, and disuse of the venom apparatus in prey capture. Such a modification seems logical since it would be difficult to use the metasoma and venom apparatus efficiently in a narrow burrow.

Anuroctonus phaeodactylus also is distinctive in having an unusually heavy body for its length. In general, a 2- to 3-gram roving vejovid would be a very large specimen, while such a weight is common in *A. phaeodactylus*. This increase in the volume-to-surface ratio perhaps is a mechanism by which this species is aided in maintaining its activity throughout the entire year.

Discussion and Conclusion

Anuroctonus phaeodactylus exhibits a very specialized burrowing behavior which helps adapt it for survival in arid regions characterized by well packed sedimentary soils. The species is broken up into numerous isolated demes in favorable areas of Central and North America. Each aggregation or deme is maintained by very specific habitat preference, the habit of permanent burrowing, and nature of young dispersal. Gene flow between demes is probably maintained only by the wandering of a few adult males during their premating migrations.

Populations are found on sloping sedimentary hills or canyon sides with greatest density occurring on southeastern exposures. Water drainage seems to be an important limiting factor to their habitation as this species is never found in the lower parts of a drainage and their burrow entrances are constructed in such a way as to shed water moving along the ground surface. Soil composition and texture are also important limiting factors, as this species lives in permanent burrows which can only be constructed in soils which can be suitably packed. Populations are most dense where vegetation is relatively sparse and where leaf litter is insignificant. In southern California, chaparral is the dominant plant community where this scorpion occurs, especially in areas kept sparse by periodic fire.

The fact that young individuals of *A. phaeodactylus* begin to burrow as soon as their exoskeleton is sufficiently hard, that burrowing is obligate, and that burrows are remarkably similar indicates that this aspect of their life history must be strongly governed by natural selection and should therefore have very important functions. The burrow serves at least four functions: a trap for food, protection from predators, protection from a temporarily unfavorable environment, and an environmental tempering mechanism. The scorpion apparently waits inside the burrow for the prey to enter. For example, on a hot day a ground-dwelling arthropod may be captured after it has entered the burrow to escape the sun. By living inside a burrow, many possible predators, such as insectivorous mammals and birds, do not have the opportunity to capture them. Also, during times of environmental extremes, such as extreme heat or cold, they will remain safe deep in the soil where conditions are not as extreme. By living 1 foot below the surface, the physical environment is greatly tempered. There will be less difference between day and night, and between winter and summer. Therefore, by burrowing, the scorpion can live under relatively constant environmental conditions of temperature, humidity, wind, and light as compared with species living on or near the ground surface. Because of this protection from environmental extremes the necessity for hibernation has been eliminated in this species.

A striking similarity exists between the life history of tarantulas and *A. phaeodactylus* in regard to burrowing. Tarantulas live in permanent burrows in similar types of habitats. The females seldom, if ever, leave the burrow during their entire life, while males, only as adults, are transient and are frequently seen migrating during the breeding season (Baerg, 1963). All observations on *A. phaeodactylus* indicate that this behavior is remarkably similar to that of the tarantula, at least in the ways described.

Anuroctonus phaeodactylus demonstrates both a morphology and a number of behavioral patterns which are specialized for burrowing. The pectines, pedipalps, and body weight in relation to size, are all distinctive and favor a permanent burrowing way of life. Behavior, such as constantly dragging the pectines over the burrow floor while traveling, as well as frequent and careful "sponge bathing," can also be considered adaptations for a burrowing existence.

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